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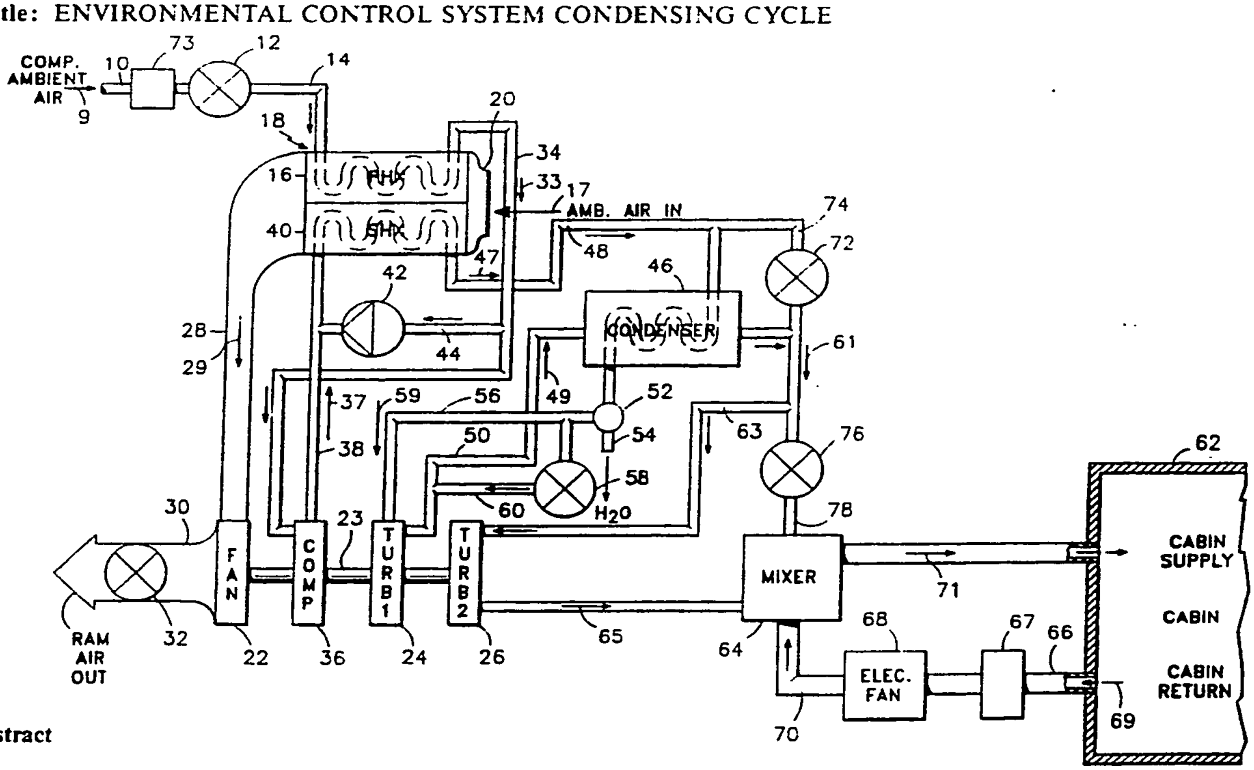
(54) Title: ENVIRONMENTAL CONTROL SYSTEM CONDENSING CYCLE



(57) Abstract

In an air cycle environmental control system, a condenser (46) removes water vapor from compressed, ambient, supply air (9) before it is expanded in a first turbine (24). The chilled outlet air (49) from the first turbine (24) is then used as coolant in the condenser (46), absorbing there the heat of vaporization of the condensed water vapor. After passing through the condenser (46), the warmed coolant is then expanded in a second turbine (26). Should the pressure of the supply air fall below predetermined levels, portions of the cycle that degrade performance or become unnecessary are bypassed.

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ENVIRONMENTAL CONTROL SYSTEM CONDENSING CYCLE

Description

Technical Field

This invention relates to air cycle environmental control systems that condition air.

Background Art

Aircraft designed to operate in rarefied atmosphere typically employ an air cycle environmental control system to cool, filter, pressurize, and otherwise condition cabin air. In most installations, compressed ambient air, provided by either the engine compressor section, the auxiliary power unit, or both, is expanded in an air cycle turbomachine, providing a cool, fresh, air supply for the cabin. The costs of this cool, fresh, air supply are twofold. First, due to the size and number of components required for their assembly, these systems can appreciably increase the gross weight of the aircraft. Second a considerable amount of energy, stored in the compressed, ambient, supply air, is needed to satisfy the cooling requirements of even an average-sized aircraft. In an industry faced with increasing fuel costs and heightened environmental concerns, considerable effort is made to reduce, without sacrificing overall system performance, both the weight and energy requirements of these systems.

Since compressed ambient air is readily available, it is a convenient source of power for airborne environmental control systems. In most systems, the compressed, ambient air is passed through a heat exchanger cooled by air from outside the aircraft, lowering its temperature to around ambient air temperature. To further lower the temperature

of th compressed ambient air, it is expanded in a turbine. If the temperature of the expanded air falls below its dew point, any water vapor entrained in it will condense. Should expansion lower further, to below the freezing point, the temperature of the compressed, ambient air, the condensed water freezes. In sufficient quantities, the resulting ice restricts flow through the system and decreases performance, possibly to the point where the system becomes inoperable.

Many prior art systems employ one or both of two techniques to ensure that no ice forms that might clog the system. The first of these approaches is to simply design the turbine such that temperature of its outlet air remains above the freezing point. Not only is it then impossible for ice to form, but the size of the heat exchanger, a bulky component accounting for a significant percentage of overall system weight, may be reduced. However, systems of this nature require far more energy to produce a desired amount of cooling than systems in which turbine outlet air temperature is allowed to fall below the freezing point.

The second approach taken in these systems is to operate the turbines below the freezing point and provide the system with the capability both to sense the presence of ice and to deliver warm deicing flow to the regions where an unacceptable level of ice accumulation is indicated. The benefit of this type of system is that the deicing mechanism is operational, and therefore extracts energy from the system, only when ice is detected. Delivering warm deicing flow, however, requires additional hardware that increases the overall weight of the system. In US Patent 3,177,679, when thermostats in the outlets of each of two turbines indicate temperatures below freezing,

valves in ducts connecting the turbine utlets with warmer air sources pen. In US Patent 4,127,011, a plenum encases the outlet of a turbine. When the temperature within that turbine outlet falls below freezing, valves open to deliver warm air into the plenum, preventing ice from accumulating on the inside surface of the turbine outlet.

An alternative to this second approach is to operate system turbines below the freezing point and mix a continuous flow of warm air with the turbine outlet air to raise its temperature. In US Patent 3,877,246, a system with two turbines employing this technique is described. The outlet air of the first turbine mixes with warm air both recirculated from the cabin and compressed, enabling it to operate below the freezing point. This mixture then expands in a second turbine. Before entering the cabin, the outlet air exhausted from this second turbine passes first through a precipitator to remove any entrained water vapor. To maintain the temperature of air downstream of the second turbine above freezing, a valve in a duct connecting the inlet of the second turbine to the outlet of the second turbine is modulated. A similar system, but with a single turbine, is described in US Patent 2,628,481. Recirculated cabin air is first filtered and then split. The first half of this split, recirculated air mixes directly with the air exiting the turbine. Water vapor entrained in this mixture is then removed in a water separator. The flow exiting the separator then mixes with the second half of the recirculated cabin air before entering the aircraft.

US Patent RE32,100 (reissue of US Patent 4,209,993) and 4,430,867 both describe single-turbine systems that also use the heat contained in recirculated air to maintain

th temperature of air downstream of the turbine above the freezing point. Before entering the turbine inlet, compressed supply air first passes through the warm path of a primary condenser, removing entrained water vapor. The dehumidified air exiting the warm path of the condenser is then expanded in the turbine. In US Patent RE32,100, the outlet air exiting this turbine then mixes with warm cabin recirculation air and passes through the cold path of the condenser. In US Patent 4,430,867, the outlet air exiting the turbine passes first into the cold path of a heat exchanger before entering the cabin. Fluid passing through the warm path of the heat exchanger passes first through the cold path of a secondary condenser located in the cabin. Recirculated air is drawn through the warm path of this secondary condenser, dehumidifying it before passing it back into the cabin. The fluid, warmed in the cold path of the secondary condenser, passes subsequently to the cold path of the primary condenser before circulating back to the heat exchanger.

The systems disclosed in both US Patent RE32,100 and 4,430,867, by providing means for the removal of water vapor from the air stream prior to expansion within the turbine, allow the turbine to operate at more efficient subfreezing temperatures. However, these systems fail to recover the heat of vaporization yielded when water vapor is condensed from the turbine inlet stream, contributing to an overall loss of cycle efficiency and cooling capacity.

Disclosure of Invention

Objects of the invention include increasing the efficiency of air cycle environmental control systems

through recovery of the h at of vap rization stored in water vapor contained in compressed ambient air.

Further objects of the invention include providing means in such systems to change the cycle for optimal system efficiency under varying ambient conditions.

According to the present invention, air exiting a first turbine of a system is expanded in a second turbine after being used to condense water vapor in the compressed ambient supply air entering the first turbine.

According further to the present invention, the syst m includes means to bypass portions of the cycle that degrade performance or become unnecessary as the characteristics of the compressed ambient air supplying the system vary.

Due to the increased thermal efficiency realized by recovering the heat of vaporization, embodiments of the present invention have either greater airflow and cooling capacity than prior art systems of the same weight and size, or airflow and cooling capacity equal to heavier and larger prior art systems.

Additionally, the first and second turbine expansion ratios may be chosen to ensure that the first turbine outlet airflow remains above freezing, as energy not extracted in this turbine will be recovered by the second. This reduces icing concerns in the condenser, allowing for only moderate deicing means.

In the dry, low pressure atmosphere encountered at cruise altitudes, the invention further provides for selectively bypassing both the first turbine stage and the condensing heat exchanger, passing flow directly to the second turbine. As the the first turbine has a smaller nozzle area than the second, and as the compressor restricts flow, bypassing these two components increases

th volume flow rate through th system. In v n lower pressure atmosphere where the nozzle area of the second turbine is too small to allow sufficient mass flow, the second turbine is also bypassed, and maximum flow through the system is attained.

The foregoing and other objects, features, and advantages of the present invention will become more apparent in the light of the following detailed description of exemplary embodiments thereof, as illustrated in the accompanying drawings.

Brief Description of Drawing

The sole Figure is a schematic diagram of an air cycle environmental control system incorporating the present invention.

Best Mode For Carrying Out the Invention

Referring now to the Figure, compressed ambient supply air 9 enters an air cycle environmental control system via a duct 10. The source of this air (not shown) may be either an auxiliary power unit, the compressor section of a gas turbine engine, or both. The flow rate of compressed air entering the system is regulated by a valve 12 connected by a duct 14 to a warm path of a primary heat exchanger 16. To cool air in this warm path, relatively cool external ambient air 17 flows into an opening 20 at the exterior of the aircraft (not shown) and through a cooling path. To maintain sufficient flow through this cooling path during low airspeed operation, a fan 22, driven by a pair of turbines 24, 26 via a shaft 23, connects to the outlet of the cooling path via a duct 28, drawing warmed external ambient air 29 through the path and

exhausting it from the aircraft via a duct 30. A valve 32 in this fan exhaust duct 16 may be modulated to regulate the cooling flow rate.

Following cooling in the warm path of the primary h at exchanger 16, primary heat exchanger outlet air 33 flows through a duct 34 to a compressor 36, also driven by the two turbines 24, 26. Compressor outlet air 37, heated by this compression step, subsequently passes via a duct 38 to a warm path of a secondary heat exchanger 40, where it is cooled by the external ambient air 17 flowing through a cooling path, similar to the aforementioned cooling means of the primary heat exchanger 16.

Secondary heat exchanger outlet air 47 exiting the warm path of the secondary heat exchanger 40 subsequently flows via a duct 48 to the condensing flowpath of a condenser 46. The temperature of the heat transfer surface within this condenser 46 is maintained at or below the desired dew point of the secondary heat exchanger outlet air 47. This dehumidifies the secondary heat exchanger outlet air 47 before it flows to the first turbine 24 via a duct 56. Cooled by expansion in the first turbine, the first turbine outlet air flows to a cooling path of the condenser 46 via a duct 50, chilling the heat transfer surfaces and absorbing the heat of vaporization of the condensed water vapor. The expansion ratio of the first turbine 24 is therefore chosen to maintain a first turbine outlet air 49 temperature high enough to avoid icing, given the mass flow rate through the system, within the warm path of the condenser 46. In most applications, the desired temperature of the first turbine outlet air 46 is between 35 and 40 degrees Fahrenheit (1.7 to 4.4 degrees Celsius). Should the actual first turbine outlet temperature fall

below the desired point, r if by some means the presence of ice is sensed in the c ndenser 46, a valve 58 opens to allow dehumidified first turbine inlet air 59 to pass through a duct 60 and mix with and warm the first turbine outlet air 49.

Numerous methods may be employed to sense the accumulation of ice. A pressure sensor (not shown) may be placed at the inlet and outlet of the warm path of the condenser 46. Should the pressure drop across the warm path exceed some predetermined level, it may be concluded that sufficient ice has formed in the path to restrict flow. As an alternative, the outlet of an orifice (not shown) connected to a cool, high pressure air source may be placed to exhaust into the warm path of the condenser 46. The size of the orifice is selected to allow only a small amount of flow to pass through it. Should flow or pressure sensors monitoring the air flowing into this orifice indicate that pressure has increased or flow has decreased, it may be concluded that ice has formed in and clogged the nozzle opening.

As secondary heat exchanger outlet air 47 passes through the condensing path of the condenser 46, the heat of vaporization of any water vapor mixed with it is recovered, upon condensation, by the first turbine outlet air 49 in the cooling path. The total recoverable energy stored in the condenser cooling path outlet air 61 is therefore the sum of this recovered heat of vaporization and any energy not recovered by the first turbine 24. To recover this energy, the condenser cooling path outlet air 61 passes through a duct 63 and expands in the second turbine 26.

To moderat th volume and temperature of th airflow passing into the aircraft cabin 62, the s cond turbine outlet air 65 passes into a mixer 64 where it is combined with recirculated cabin air 69. A fan 68 draws this recirculated air 69 from the cabin 62 through both a duct 66 and a filter 67. The speed of the fan 68 is controlled to provide the mass flow rate of recirculation air 69 through a duct 70 and into the mixer 64 required to satisfy overall circulation requirements.

The system according to the present invention is also able to accommodate changes in ambient and operating conditions which would otherwise reduce overall system operability and efficiency. Should pressure of the compressed ambient air 9 be too low, mass flow, sensed, for example, by a hot wire anemometer 72, drops below the level necessary to satisfy cabin fresh air flow requirements. A primary bypass valve 72 then opens, allowing flow to bypass both the condenser 46 and the first turbine 24, circulating, through a duct 74, secondary heat exchanger outlet air 47 directly to the second turbine. The primary bypass valve 72 typically opens when the aircraft is at the high altitudes encountered at cruise, when the external ambient air 17, and therefore the supply air 9, are low in pressure and humidity. The expansion ratios and nozzle sizes of both turbines 24, 26 have been selected to optimize system performance in the higher pressure ambient air found at lower altitudes where humidity is a concern.

The second turbine is designed to expand air previously expanded by the first turbine, and therefore has a larger nozzle far less restrictive to flow than the first turbine nozzle. Flow passing directly to the second turbine 26 is therefore much less restricted than flow

passing first to th condenser 46 and first turbine 24. By decreasing restriction to flow, great r volume flow rates may be sustained during periods when supply air pressure is low, allowing a sufficient mass flow rate of air to enter the cabin.

Should the primary bypass valve 72 be fully open, and the hot wire anemometer 73 indicate that the mass flow rate of compressed ambient air 9 is still below the minimum rate specified for the system, a secondary bypass valve 76 also opens. In addition to the first turbine 24 and the condenser 46, flow then also bypasses the second turbine 26, passing secondary heat exchanger outlet air 47 directly through a secondary bypass duct 78 and into the mixer 64. In this situation, as neither turbine 24, 26 is driven, the compressor 36 and fan 22 stop. The compressor 36 then acts as a flow restriction, and the pressure at the compressor outlet drops below the inlet pressure. This opens a check valve 42 located in a duct 44 connecting the inlet to the outlet of the compressor, allowing primary heat exchanger outlet air 33 to bypass the compressor and flow directly to the secondary heat exchanger 40. Under these conditions, therefore, compressed ambient air 9 passes directly from the primary 16 to the secondary 40 heat exchanger and into the mixer 64, allowing maximum volume flow through the system.

Even when the mass flow rate of the compressed ambient air 9 is sufficient, the secondary bypass valve 76 can be modulated to regulate the cooling capacity and volume flow through the system. Should either the volume flow rate or the temperature of air 65 exiting the second turbine outlet be too low, the secondary bypass valve 76 is opened.

Although the invention has been shown and described with resp ct to exemplary embodim nts th reof, it should be understood by those skilled in the art that various changes, omissions, and additions may be made therein and thereto, without departing from the spirit and scope of the invention.

CLAIMS

1. An air cycle environmental control system for conditioning air within an enclosure, comprising:

means for dehumidifying compressed, ambient, water-vapor bearing, supply air;

means for supplying dehumidified outlet air from said dehumidifying means to a first turbine;

means for supplying outlet air from said first turbin to a cooling path of said dehumidifying means; and

means for supplying outlet air from said cooling path to a second turbine.

2. The system according to claim 1, wherein said first turbine has an expansion ratio such that the temperature of said first turbine outlet air is between the dew point of said supply air and the freezing point of said dehumidifying means.

3. The system according to claim 1, including means for bypassing a portion of said dehumidified outlet air past said first turbine.

4. The system according to claim 1, including means for supplying a portion of said supply air directly to said second turbine.

5. The system according to claim 1, including means for supplying a portion of said supply air directly to the outlet of said second turbine.

6. An air cycle control system, comprising:

a source of compr ssed, ambient, water-vapor bearing, supply air;

a primary heat exchanger receiving and cooling said supply air, said primary heat exchanger also being suppli d with cooler ambient air in heat exchange relationship with said supply air;

a compressor receiving outlet air from said primary heat exchanger, said compressor driven by a first and a second turbine;

a secondary heat exchanger receiving and cooling outlet air from said compressor, said secondary heat exchanger also being supplied with cooler ambient air in heat exchange relationship with said compressor outlet air;

a condenser receiving and removing vapor from outlet air from said secondary heat exchanger, said condenser also being supplied with a coolant fluid in heat exchanger relationship with said secondary heat exchanger outlet air;

said first turbine receiving and expanding outlet air from said condenser;

means for passing said outlet air from said first turbine through said condenser as said coolant fluid; and

said second turbine receiving and expanding air passed through said condenser as said coolant fluid.

7. The system according to claim 6, including:

means to detect icing within said condenser; and

means, responsive to said ice detection means, for bypassing a portion of said condenser outlet air past said first turbine.

8. The system according to claim 6, including means to determine the mass flow rate of said supply air.

9. The system as in claim 8, including means, responsive to said mass flow rate determination means, for delivering a portion of said secondary heat exchanger outlet air directly to the inlet of said second turbine.

10. The system as in claim 8, including means, responsive to said mass flow rate determination means, for delivering a portion of said secondary heat exchanger outlet air directly to the outlet of said second turbine.

11. A method for conditioning air within an enclosure, comprising the steps of:

condensing and removing water vapor from compressed, ambient, supply air;

expanding air dehumidified in said condensing step in a first turbine;

employing air expanded in said first turbine as coolant in said condensing step; and

expanding said coolant warmed in said condensing step in a second turbine.

12. The method according to claim 11, further comprising the step of evaluating the mass flow rate of said supply air.

13. The method according to claim 12, further comprising the step of supplying, responsive to the mass flow rate of said supply air falling below a first preselected level, said supply air directly to the inlet of said second turbine.

14. The method according t claim 12, further comprising the step of supplying, responsive to the mass flow rate of said supply air falling below a second preselected level, said supply air directly to the outlet of said second turbine.

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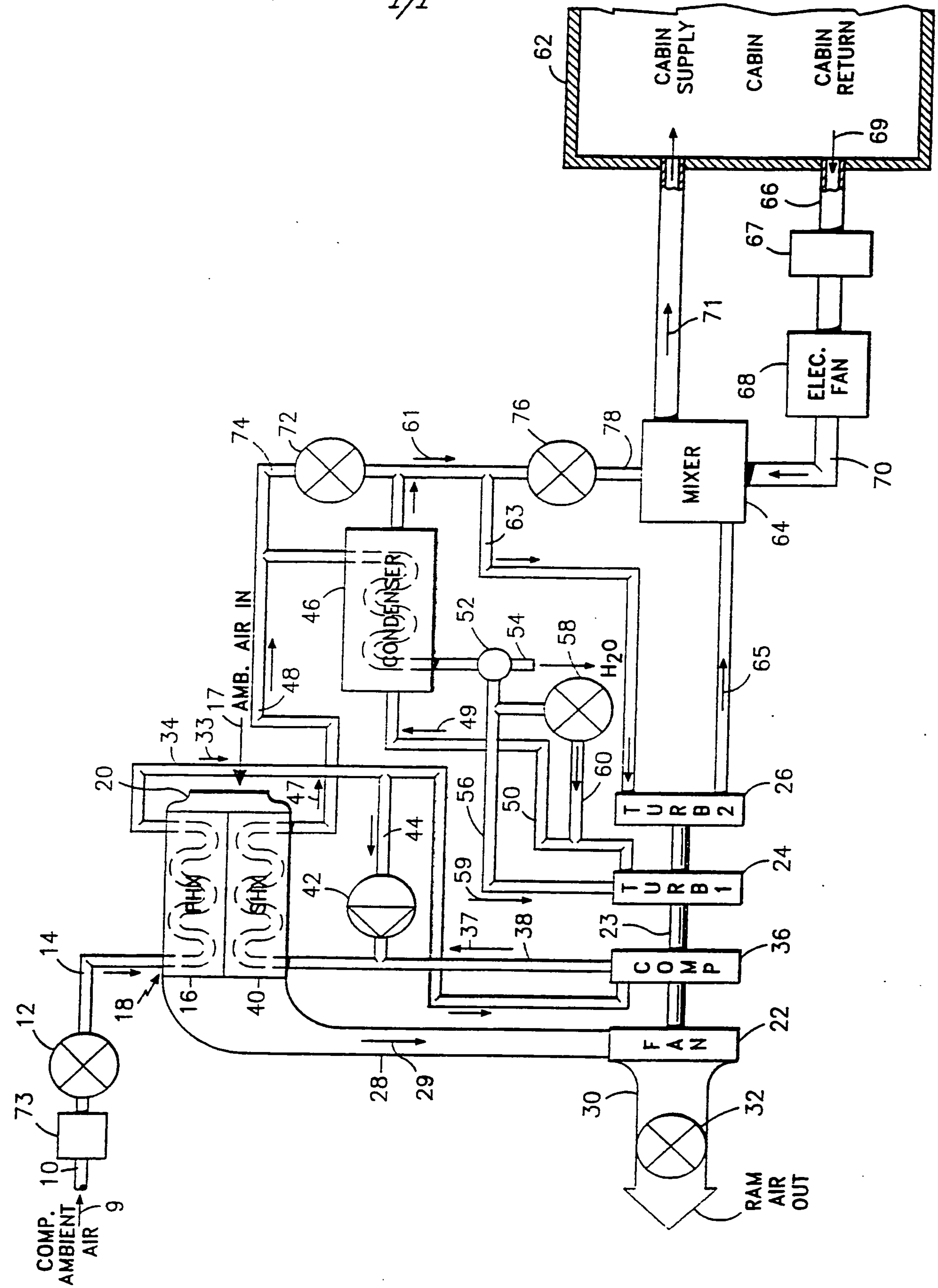
CABIN SUPPLY
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INTERNATIONAL SEARCH REPORT

International Application No PCT/US 91/03529

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all)[6]

According to International Patent Classification (IPC) or to both National Classification and IPC

Int.Cl. 5 B64D13/08

II. FIELDS SEARCHED

Minimum Documentation Searched[7]

Classification System	Classification Symbols
Int.Cl. 5	B64D ; F25B ; B60H ; F24F

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched[8]

III. DOCUMENTS CONSIDERED TO BE RELEVANT[9]

Category °	Citation of Document, [11] with indication, where appropriate, of the relevant passages [12]	Relevant to Claim No.[13]
A,P	WO,A,9100483 (ALLIED-SIGNAL INC.) 10 January 1991 see page 4, line 14 - page 5, line 18 see page 13, line 20 - page 14, line 27; figure 1 ---	1, 6, 11
A	US,A,4209993 (RANNENBERG) 01 July 1980 see column 2, line 50 - column 3, line 31 see column 3, line 62 - column 4, line 45; figure 1 (cited in the application) ---	1, 3, 6, 7, 11
A	US,A,3877246 (SCHUTZE) 15 April 1975 see column 1, lines 35 - 56 see column 4, lines 16 - 64; figure 2 (cited in the application) ---	1, 6, 11

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° Special categories of cited documents : [10]

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IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
04 SEPTEMBER 1991	11. 09. 91
International Searching Authority	**Signature of Authorized Officer**
EUROPEAN PATENT OFFICE	RIVERO C.G. Rivero

III. DOCUMENTS CONSIDERED TO BE RELEVANT (CONTINUED FROM THE SECOND SHEET)		
Category °	Citation of Document, with indication, where appropriate, of the relevant passages	Relevant to Claim No.
A	GB,A,2027874 (VEREIGNIGTE FLUGTECHNISCHE WERKE-FOKKER GMBH) 27 February 1980 see page 1, line 47 - page 1, line 32; figure 1 ---	1, 6, 11

ANNEX TO THE INTERNATIONAL SEARCH REPORT ON INTERNATIONAL PATENT APPLICATION NO. US9103529

SA 48199

This annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report.
The members are as contained in the European Patent Office EDP file on 04/09/91
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